EARLY BUSINESS CASES FOR H2 IN ENERGY STORAGE AND MORE BROADLY POWER TO H2 APPLICATIONS

Launch Event

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Objectives of P2H Early BizCases

Identify bankable Power-to-Hydrogen business cases for 2017-25 in the EU-28

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1. Within the EU-28, **identify locations with favorable electricity conditions** for P2H systems (at sub-national level)

2. Study **three concrete P2H business cases** for a specific location and application (industry, mobility), quantifying key performance indicators (CAPEX, revenues, margin,..)

3. Derive **boundary conditions for profitability** and assess **replicability potential** in the EU-28

Key message:

There are bankable business cases for PtoH in Europe already today

- By 2025, the European market for PtoH is estimated at a cumulative 2.8 GW, representing a market value of 4.2B€ and 400 ktons H2 per year.
- Bankability can be achieved by complementing hydrogen sales with electricity grid flexibility services
- Combining PtoH for mobility/industry applications and gas grid injection is more cost-effective than stand-alone injection
- Gas grid injection is a risk mitigation instrument until H2 demand picks up
- The Clean Energy package is a unique opportunity to create a market for PtoH in oil refineries
- PtoH is a practical and system-beneficial way to value excess of RES but requires a long-term view on grid fees, taxes and levies to enable bankability

(1) See ENTSO-E (2016), Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe.

Agenda

- Costs
- Revenues
- Business cases
- Replicability

Early business cases are found in low-cost electricity areas (≤ 40-50 €/MWh), driven by: (1) low burden of grid fees, taxes & levies (2) local price discounts

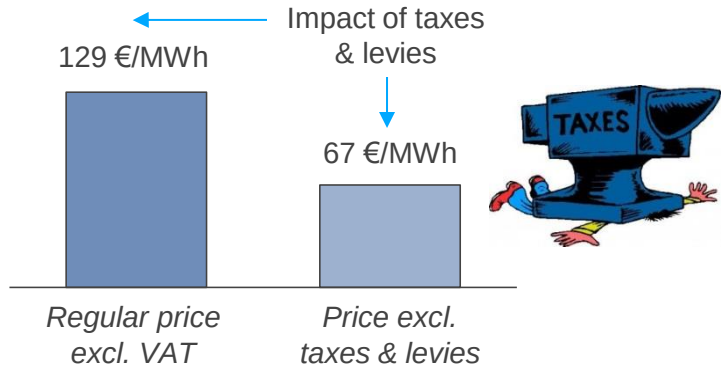
Total (baseload) electricity price ≡ Total cost of supplying electricity to the electrolyser (≠ wholesale electricity price); includes grid fees, taxes, levies and green certificates for electricity purchased from the grid

Uncontestable part of electricity bill:

- (i) grid fees
- (ii) taxes
- (iii) levies

- Driven by regulation
- (Partial) exemptions already in place in some EU member states:
  - Taxes & levies: electro-intensive consumers
  - Grid fees: storage (incl. H2) if operated in system-beneficial mode

Electricity price of industrial consumer in Germany (2016)[1]

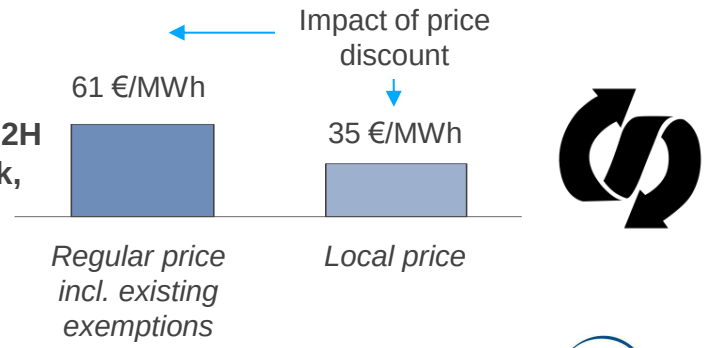


Costs related to electricity supply

"wholesale price component"

- Driven by (national/regional) wholesale price → fundamental drivers such as electricity demand and gas / coal / carbon price
- Can also be driven by grid congestion triggering local price discounts → example: reward flexibility to avoid congestion or reduce RES curtailment

Simulated price of P2H system in Herrenwyk, Germany (2025)

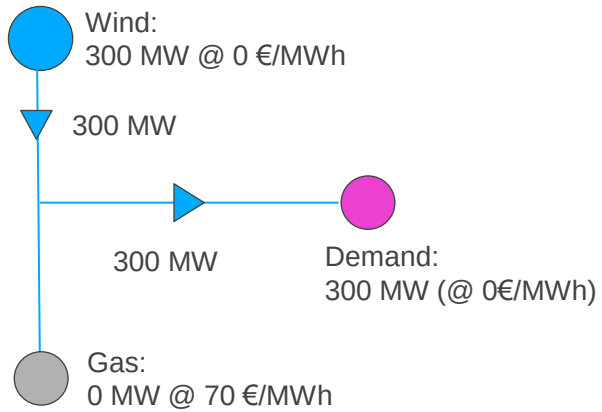


(1) Source; Eurostat, industrial electricity price, consumption band ID (2-20 GWh/yr)

Network congestion can lead to local price discounts

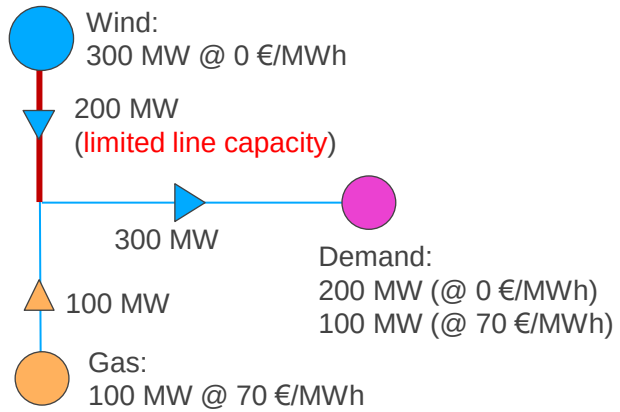
To benefit from discounts, electrolysers need to be placed close to the source of congestion

Pure market view



- Infinite line capacity
- Demand fully covered by wind resources; gas not used
- **Does not account for potential grid bottlenecks**

Market & grid view



- Finite line capacity
- Demand covered by wind and gas
- Excess of wind power → **curtailment**
- **Local overproduction is predominant cause of network congestion in Europe today**

Consequences

- Local overproduction can be tackled by curtailment or flexible load (increased consumption)
- With intermittency cost increasingly borne by RES producers, there is an opportunity to access this low-cost electricity locally
- Conservative assumption: access curtailed RES at a price discount of 60% (compared to system price in that hour)
- Quantification requires in-depth grid modelling, performed for 5 countries:

	FR	DE	GB	DK	IT
# Nodes	1360	815	1988	311	67
# Power plants	1953	1994	388	1170	42

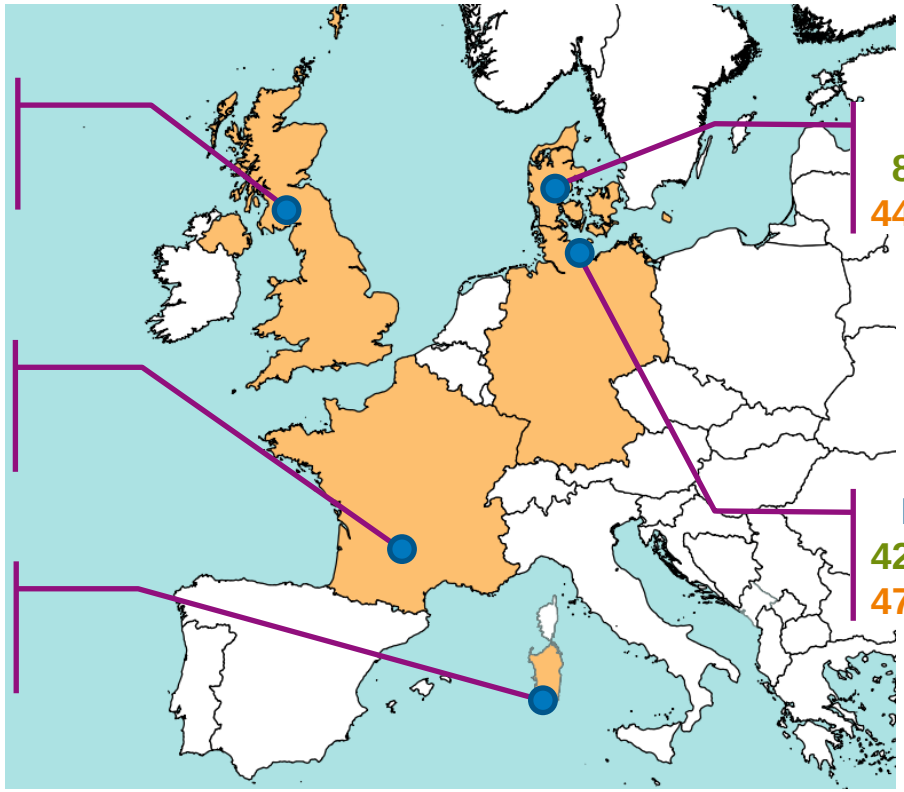
For 5 EU member states, locations with low-cost electricity were identified

Congested areas are found where there is local overproduction of RES

Tongland (UK)
71 GWh (20 %)
117 GWh (20 %)

Albi (FR)
24 GWh (9 %)
72 GWh (15 %)

Sarroch (IT)
0 GWh (0 %)
1.4 GWh (0 %)



Trige (DK)
89 GWh (5 %)
442 GWh (13 %)

Lübeck (DE)
428 GWh (59 %)
475 GWh (40 %)

Selected subnational locations with low-cost electricity
Numbers: local curtailment frequency (% year[1]) 2017 / 2025

Comments

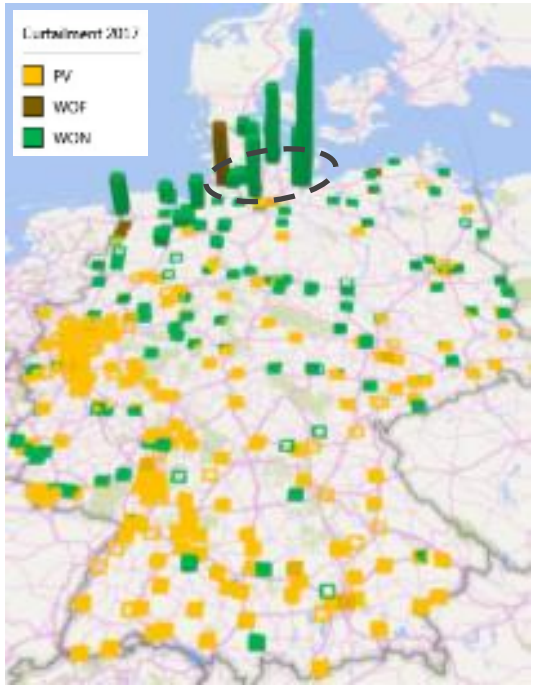
- Simulations with grid constraints show significant RES curtailment
- National level: mostly below 2% of total RES production, except for Denmark
- Node-level [HV/MV transformer]: massive curtailment shares in certain areas, up to 40%
- Curtailment occurs throughout the year in some locations

Important note: These areas are unique opportunities based on their RES curtailment potential. They are not representative of the rest of the country.

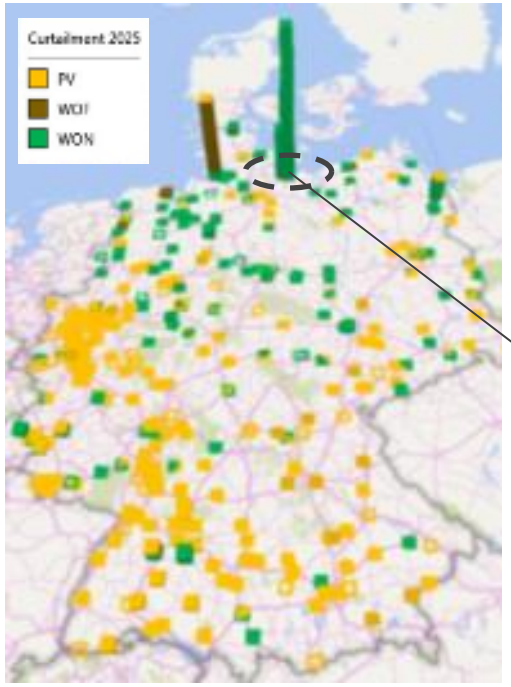
(1) Frequency refers to the number of hours per year when partial curtailment occurs, i.e. when at least 1% of the production is curtailed.

RES curtailment is a pressing issue but linked to specific areas, as the example of Germany shows

2017



2025



Curtailment at national level

2017: 2,124 GWh (1.8% of prod.)

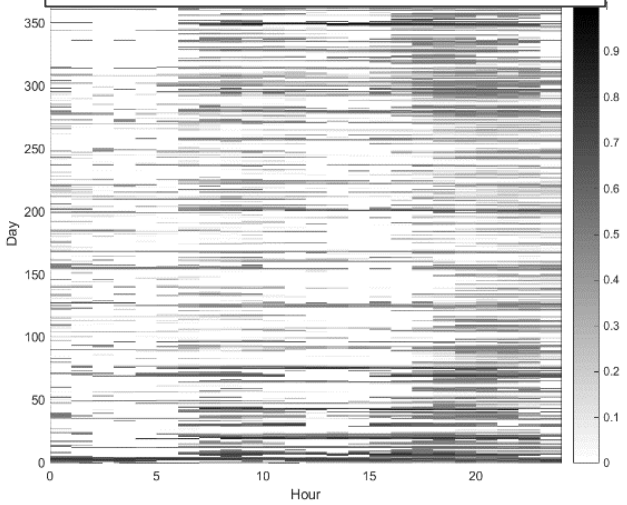
2025: 1,702 GWh (0.9% of prod.)

Interesting areas for an electrolyzer

Comments

- **Significant curtailment at national level (~2% in 2017), but no increase expected towards 2025**
- **Onshore wind** is the most **curtailed RES**:
  - Areas with high curtailment all located in Northern DE
  - Some offshore wind curtailment
  - Solar curtailment is minor
- Recommended area for electrolyser: Herrenwyk (near Lübeck)

Curtailment Profile



360 MW wind farm

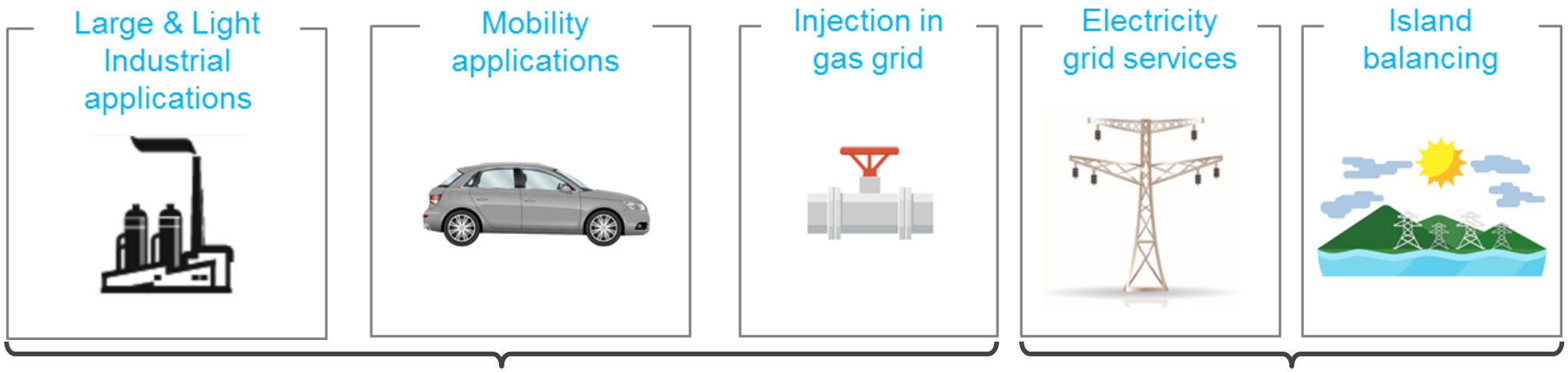
Up to 40% of RES production curtailed

Curtailment in 40-60% of the hours of the year

Agenda

- Costs
- Revenues
- Business cases
- Replicability

Power-to-Hydrogen potential revenues streams: Electrical grid services should not be considered as stand-alone applications



Revenues from **hydrogen sales**

PtoH application	Potential revenues [k€/MW/year]
Refineries, without carbon penalty	237 – 512
Refineries, with carbon penalty	792 – 1068
Light industry market (delivery by trailer)	499 – 1235
Mobility (delivery to the HRS)	526 – 920
Hydrogen injection into gas grid based on national biomethane injection tariff[1]	171 – 350*

Revenues from **grid services**

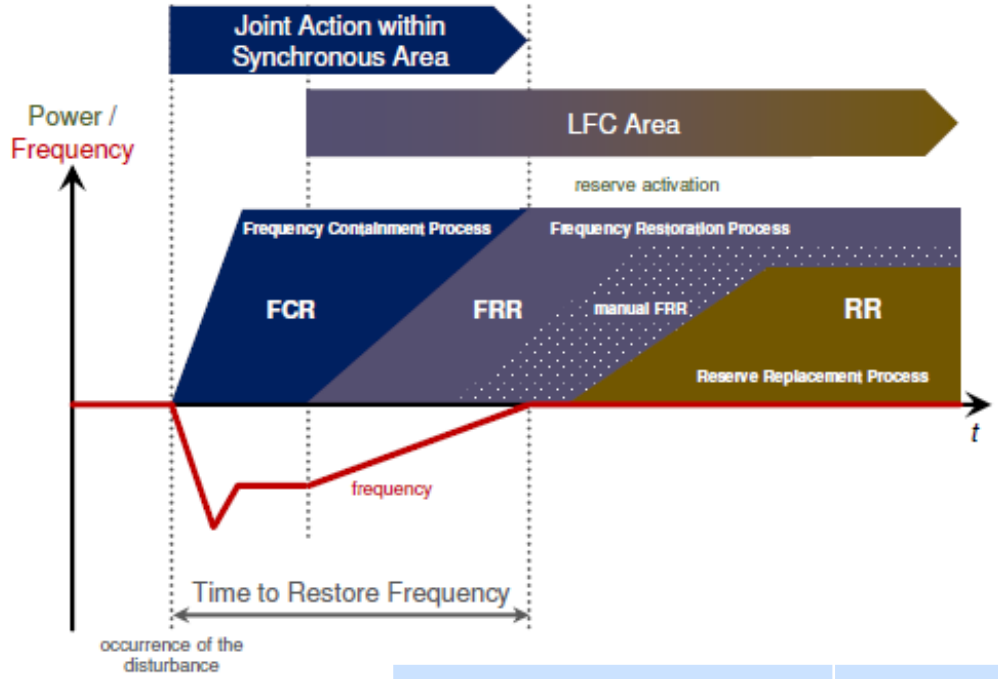
PtoH application	Potential revenues [k€/MW/year]
Balancing services	2 -17
Frequency control services	70 - 224
Distribution grid services	< 1

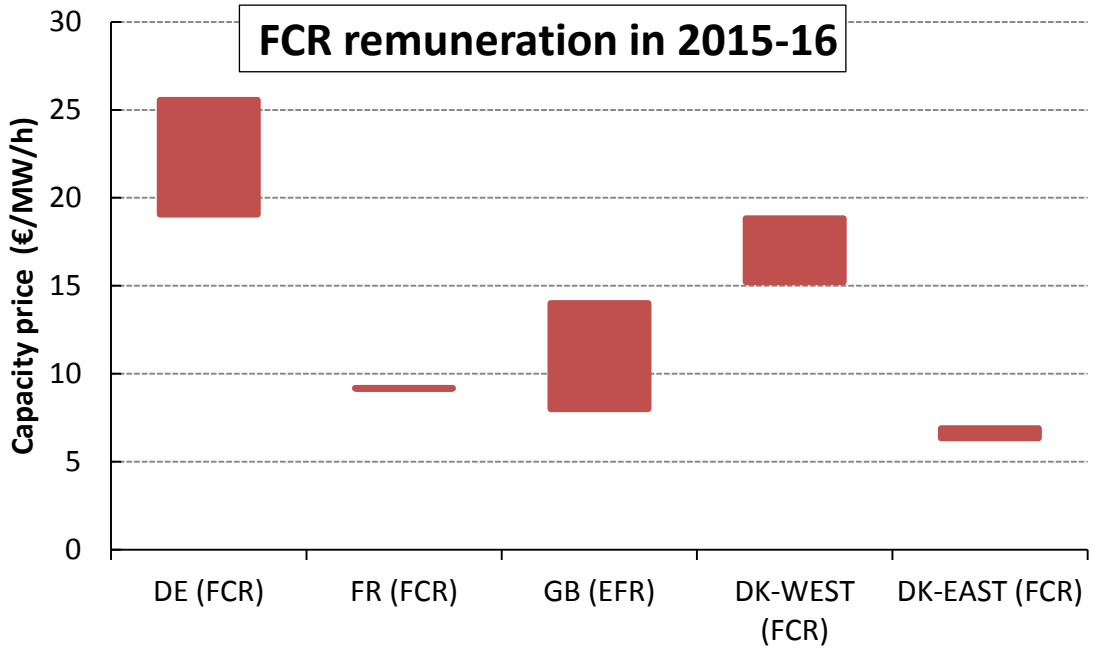
Primary applications
Secondary applications (combinable with primary applications for little extra cost)

*Biomethane injection tariff can vary significantly depending on injection capacity and feedstock. The study considers a realistic lower revenue for hydrogen gas grid injection.

* For the comparison, the potential revenues is normalised to a 1MW PEM electrolyser at 90% utilisation rate.

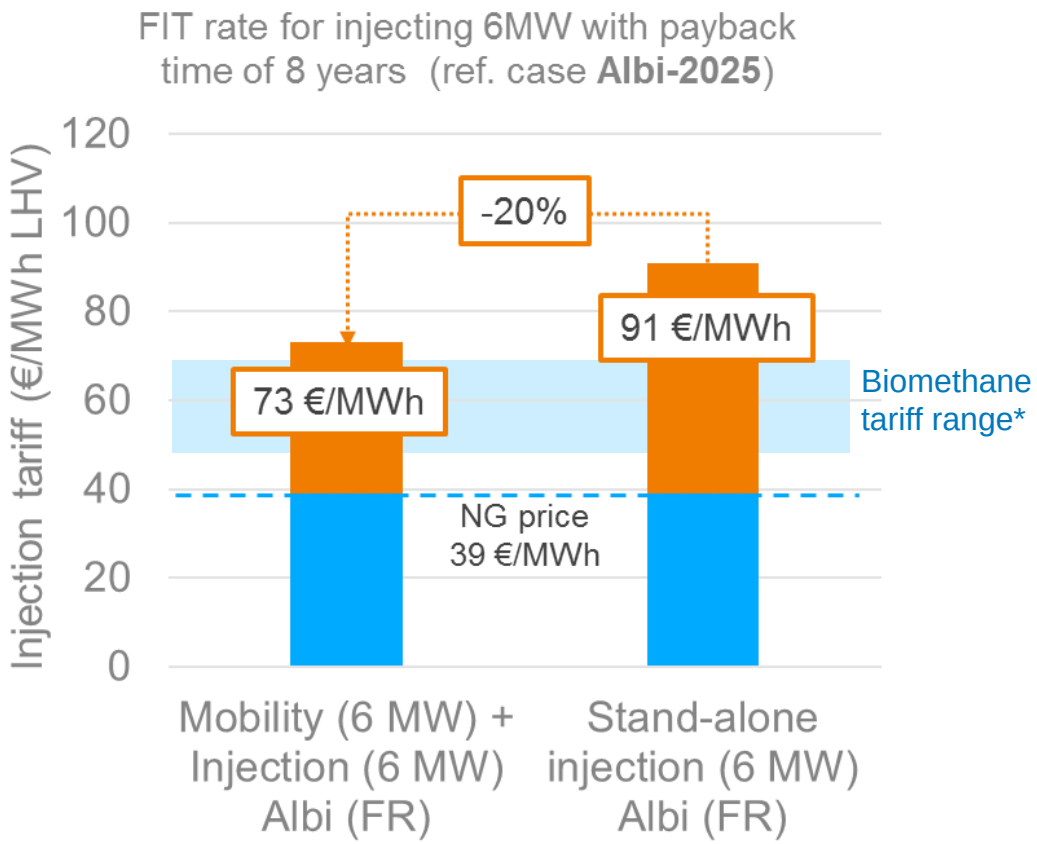
Electrolysers can offer low-carbon grid services, often remunerated by availability (capacity), effectively decreasing the electricity price





Frequency Containment Reserve (FCR)	▪ Joint action across synchronous area → harmonized technical requirements ▪ Minimum bid size ≤1 MW ▪ Activation time (≤30sec) technically feasible ▪ Often symmetrical provision (upward = downward) ▪ Often remunerated by availability (= capacity price)

Combining PtoH for mobility/industry applications and injection is more cost-effective than stand-alone injection for greening of natural gas



1

Green H_2 gas grid injection lowers the carbon footprint of natural gas and should thus be **eligible for feed-in tariffs** in line with existing supporting regimes for bio-methane.

2

Combining injection with mobility or industry reduces the level of feed-in tariff needed.
The bulk of the electrolyser CAPEX is paid by mobility or industry clients. The injection tariff only needs to cover marginal injection costs (and very limited injection-specific CAPEX).

For this reason, H_2 injection into gas grid is considered as a secondary application

Should the stand-alone injection business case have a tariff of 73 €/MWh, the payback time will more than double to > 16 years.

* Most national biomethane tariff in the selected regions ranges from 45 to 70 €/MWh LHV

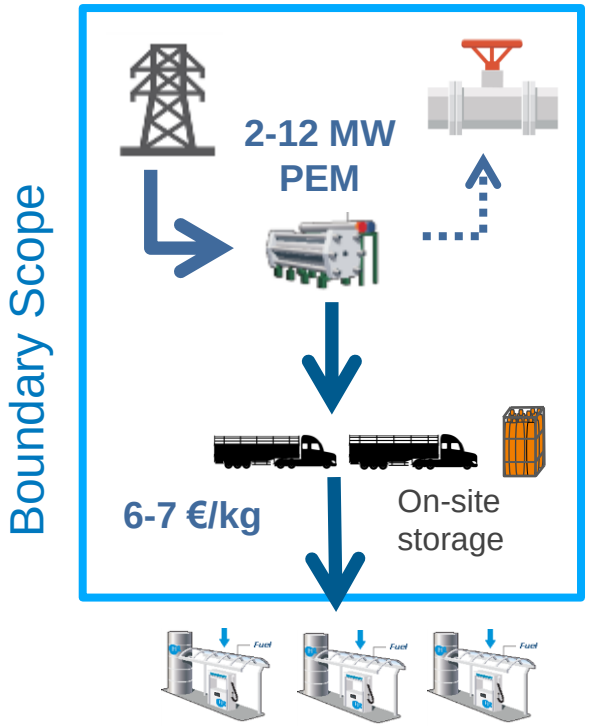
Agenda

- Costs
- Revenues
- Business cases
- Replicability

Three different business cases were analysed in three regions both 2017 and 2025

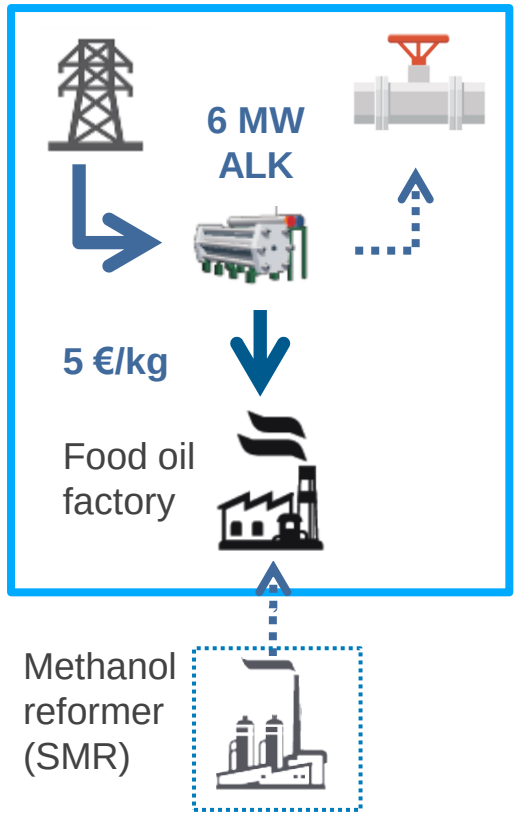
On-site production for mobility can generate profitable business cases but is excluded due the fact it has been covered intensively in previous studies.

Semi-Centralised production for mobility
(Albi-FR)

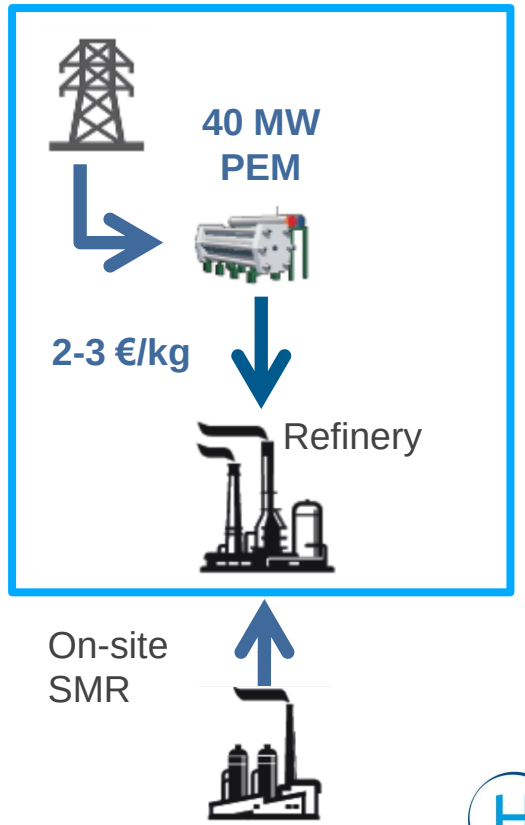


Regional network of hydrogen stations

Light industry
Food oil factory
(Trige-DK)



Large industry
Refinery
(Lübeck-DE)



CAPEX assumption of boundary scope: SC mobility: 3660 k€/MW (2017); 1900 k€/MW (2025) / Food industry: 1760 k€/MW (2017); 1400 k€/MW (2025) / Large industry: 1480 k€/MW (2017); 960 k€/MW (2025)

Bankable business cases were found in the best locations



WACC on CAPEX: 5% Project lifetime: 20 years	SC mobility (Albi, France)		Food industry (Trige, Denmark)		Large industry (Lubeck, Germany)	
	2017	2025	2017	2025	2017	2025
Primary market H2 volume (t/year)	270	950	900	900	3 230	3 230
Average total electricity price for prim. market (€/MWh)	44	45	38	47	17	26
Net margin without grid services (k€/MW/year)	**39**	**71**	**228**	**248**	**-146**	**30**
Net margin with grid services (k€/MW/year)	**159**	**256**	**373**	**393**	**-13**	**195**
Share of grid services in net margin (%)	**75%**	**72%**	**39%**	**37%**	**-**	**85%**
Payback time without grid services (years)	**11.0**	**9.0**	**4.6**	**3.7**	**-**	**8.4**
Payback time with grid services (years)	**8.0**	**4.5**	**3.4**	**2.7**	**-**	**3.5**
Key risk factors	• Taxes & Grid fees • H2 price • Size of fleets • Injection tariff • FCR value		• H2 price • Taxes & Grid fees • FCR value		• Taxes & Grid fees • FCR value • Carbon price	

Profitable stand-alone primary applications have a payback time ranging between 4 and 11 years.
Providing grid services can reduce payback time by 30-50%.

Net margin = Revenue – (aCAPEX + OPEX)
Payback time = Gross margin / CAPEX

Deep dive on Refinery in Germany (Lübeck / Hemmingstedt)

Context, Local refinery and Scenario

Local context

- **Four local refineries** near Lübeck
  - 3 in Hamburg @ 70 km from Lübeck
  - 1 in Hemmingstedt / Heide @ 110 km from Lübeck

Local refinery

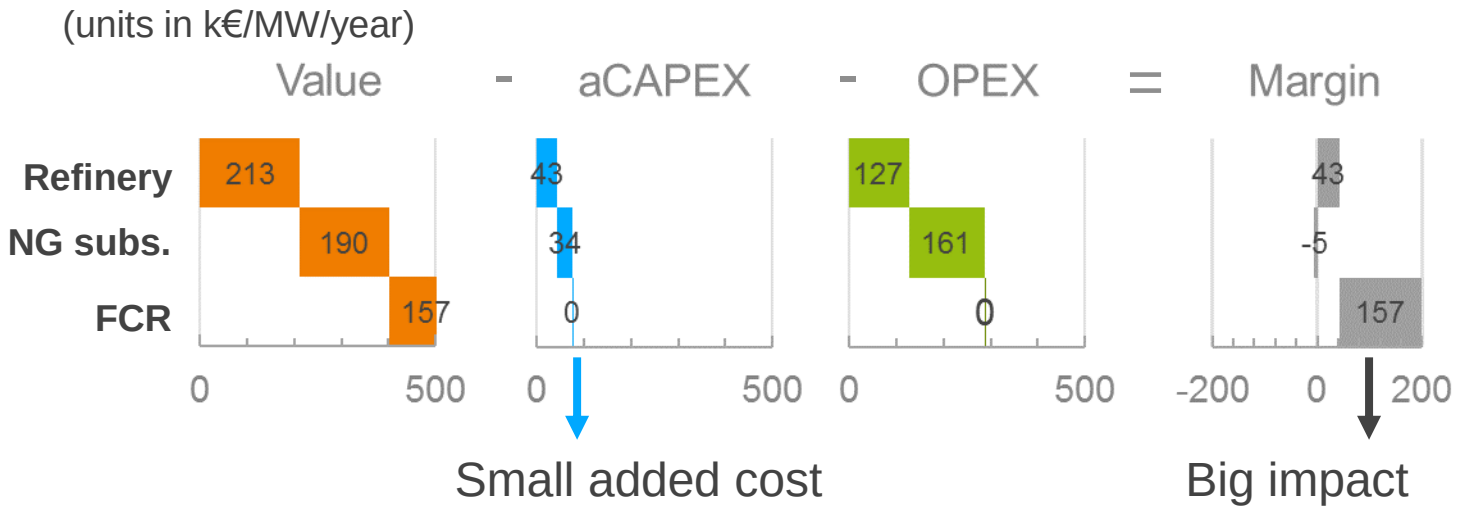
- **Heide refinery** is the one with the highest H_2 demand with 3.4 t/h (**30 000 t/year**)
- On-site SMR is considered to supply the current H_2 demand

Scenario

- Focus in 2025 on a multi-MW electrolyser project **to supply part of increasing H_2 demand** and **to reduce carbon footprint of fuel production**. The electrolyser complements local SMR.
  - 2017 & 2025: 3230 t/year (50% of increasing demand) → 20 MW electrolyser
  - The PtoH system is oversized by 200% to compete against the SMR production

PtoH can compete with H_2 production from SMR at big volume

Main parameters	2025
Grid fees, taxes, levies and Guarantee of origin (DE)	1.7 €/MWh (EnWG §118)
Grid service value	19 €/(MW.h) (FCR)
Carbon penalty	80 €/tCO_2 [1]
Value H_2 from SMR incl. carbon penalty	2.6 €/kg (prim.) 2.4 €/kg (NG subs.)
Primary market size	3 230 t/year → 20 MW
Unit sizing	200% w/ NG sub.
Technology	PEM
Op. time and total elec. price (prim.)	48% @ 26 €/MWh
Op. time and total elec. price (NG Sub.)	47% @ 34 €/MWh
H2 production cost	2.3 €/kg
Payback time	3.5 years



NG substitution allows valorisation of remaining electrolyser capacity by bringing additional revenues from electrical grid services.

PtoH production cost can be competitive against SMR. **Payback time with grid services is 3.5 years**.

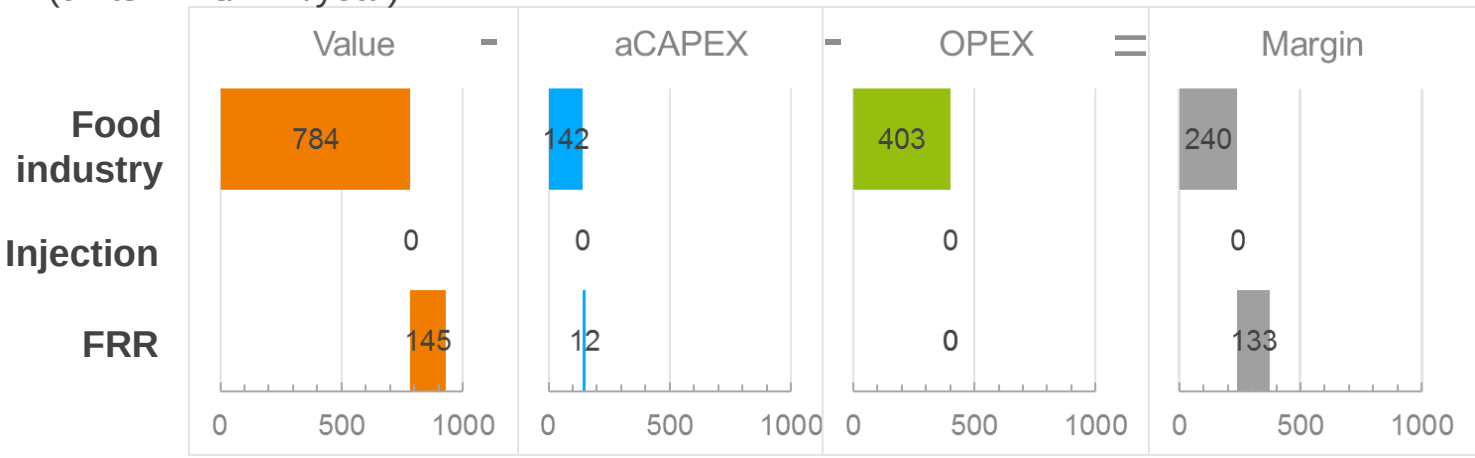
1 Considering a transposition of the French carbon floor price to EU states.

Food industry business case profitability

Main parameters	2017
Grid fees, taxes, levies and Guarantee of origin (DK)	11 €/MWh
Grid service value	17 €/(MW.h) (FRR)
H_2 market price	5 €/kg

Primary market size	900 t/year → 6 MW
Unit sizing	100% w/o Injection
Technology	ALK
Op. time and total elec. price (prim.)	95% @ 38 €/MWh
H2 production cost	3.5 €/kg
Payback time	3.4 years

(units in k€/MW/year)



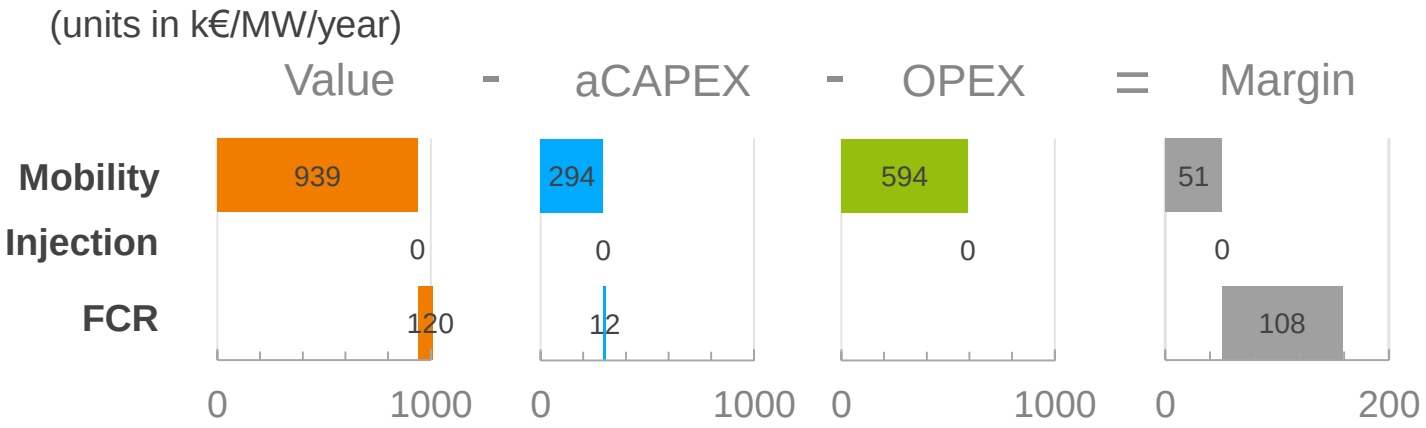
Light/food industry as a primary application for PtoH is **already a profitable and existing market**.
However, PtoH can benefit from providing grid services to generate additional revenues which can **boost the net margin by 39% at little additional investment.**

Asymetric grid services benefit to ALK electrolyser by taking advantage of their cheaper cost.

1 Considering a transposition of the French carbon floor price to EU states.

Semi-centralised production for mobility business case profitability

Main parameters	2017
Grid fees, taxes, levies and Guarantee of origin (FR)	13 €/MWh (incl. partial exemption because of electro-intensive status)
Grid service value	18 €/(MW.h) (FCR)
HRS distance	20 km one-way
H_2 market price	7 €/kg
Primary market size	270 t/year → 2 MW
Unit sizing	100% w/o injection
Technology	PEM
Op. time and total elec. price (prim.)	95% @ 44 €/MWh
H2 production cost	6.7 €/kg
Payback time	8 years

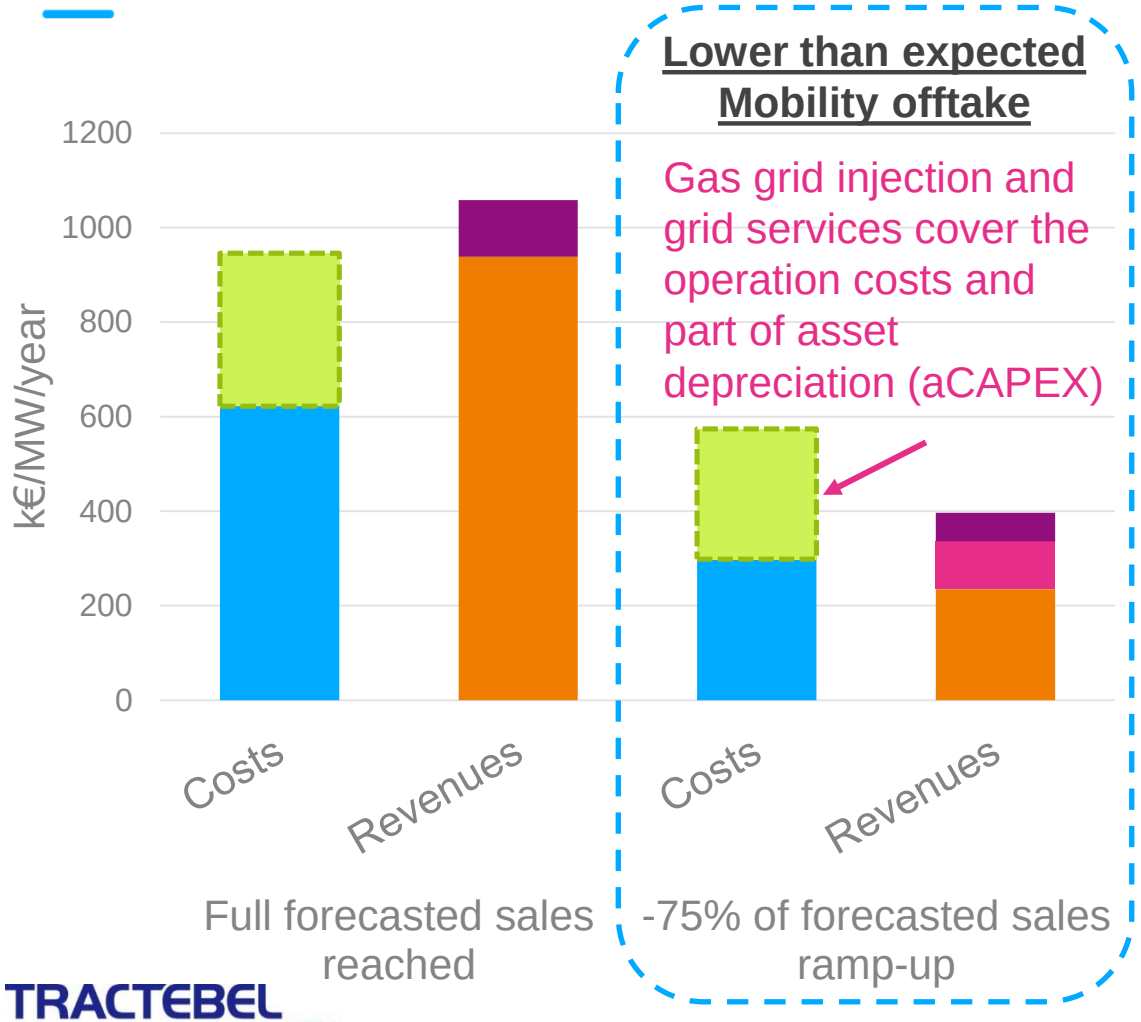


Mobility as a primary application for PtoH can be **profitable today at large volume**.

Provision of grid services can **boost significantly the net margin by 75% at little additional investment.** This will accelerate the **payback time from 11 to 8 years.**

1 Considering a transposition of the French carbon floor price to EU states.

Gas grid injection is a short-to-mid-term risk mitigation instrument through the valley of death for mobility market



Gas grid injection is an enabler of Power-to-Hydrogen for mobility applications

- Gas grid injection is a **complementary application** that can **increase the revenues** of an electrolyser used for mobility or industry.
- Gas grid injection **helps mitigate the risk of lower-than-expected mobility demand** ("valley of death") **covering the operation costs and part of asset depreciation towards break-even.**

aCAPEX
OPEX
Grid services
Injection
Primary

Mobility business case
Forecasted demand: 270 t H_2/year
2 MW PEM in FR (Albi) 2017
Injection tariff @ 90€/MWh LHV

Agenda

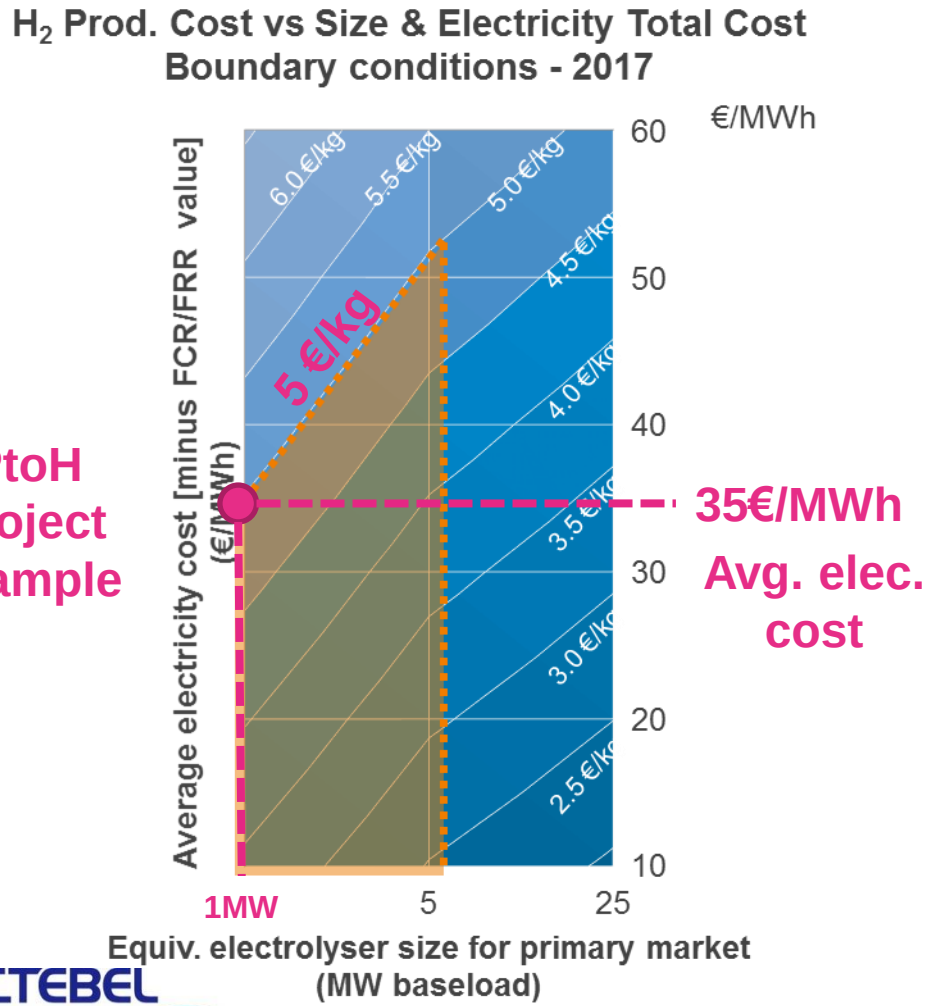
Costs

Revenues

Business cases

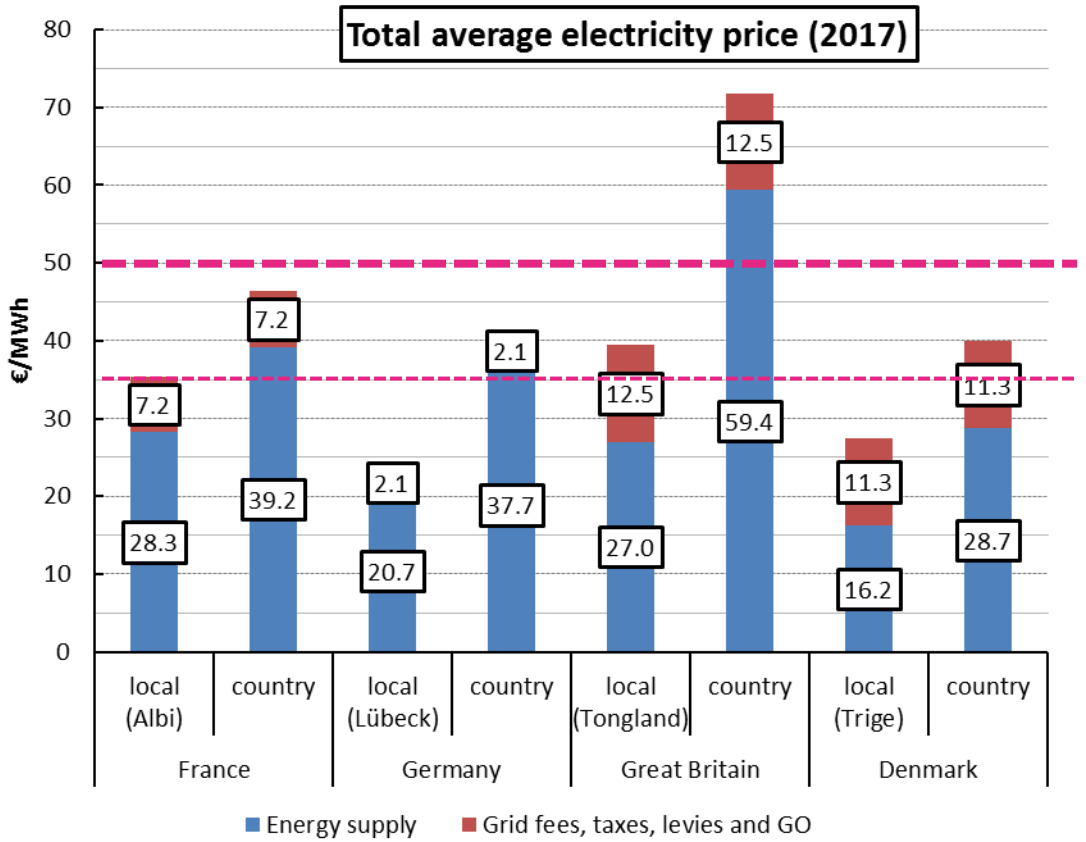
Replicability

Rule of thumb: PtoH business cases profitability depends on:
(1) primary market size, (2) hydrogen selling price and (3) average electricity cost



PtoH project example

35€/MWh
Avg. elec. cost



Grid services revenue
15 € / (MW.h)

50€/MWh

35€/MWh

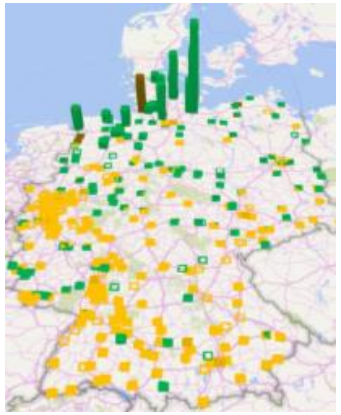
These graphs can be used by project developers to pre-evaluate business cases for suitable location and bankability.

From boundary conditions to market potentials: 3 Business Cases → 4 Countries → EU-28

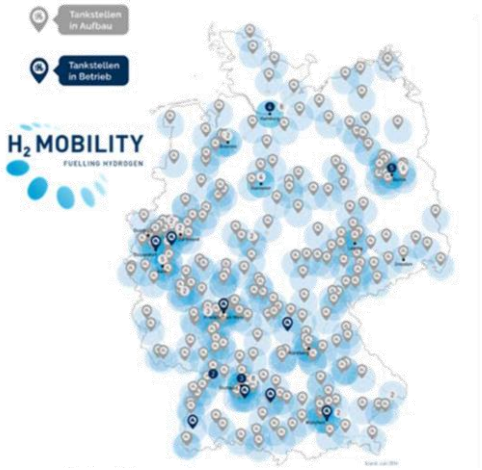
Albi
Trige
Lübeck

Geographical match between low-cost H_2 supply (→ discounted electricity) and H_2 demand

RES curtailment location



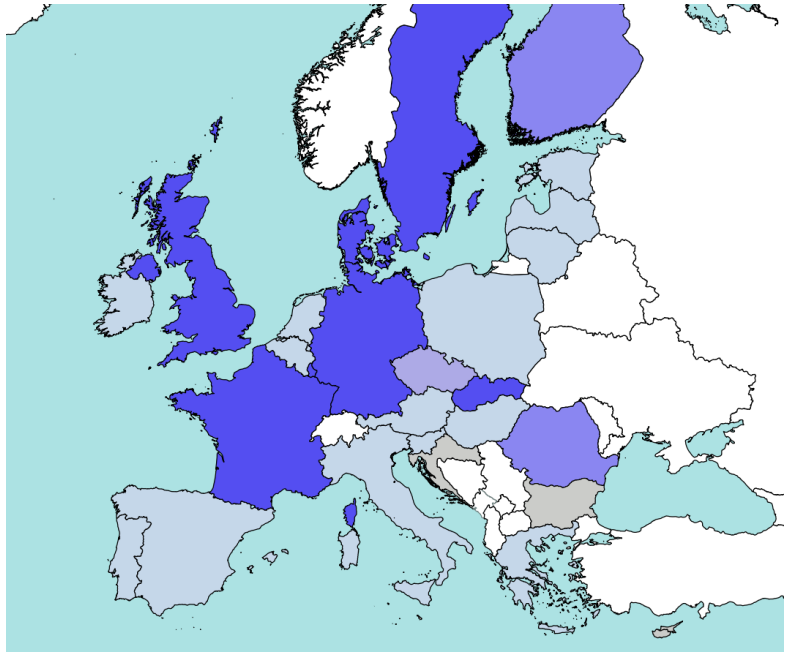
H_2 demand location (SC mobility)



FR, DE
DK, GB

Scale-up based on price indexation and country electricity consumption

EU-28



Potential FCR revenues:
capped to 335 MW electrolyser capacity[1]
(~20% of FCR market in FR, DE, DK, GB)

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(1) per business case, i.e. 1005 MW for all three business cases.

By 2025, the European market for PtoH is estimated at a cumulative 2.8GW, representing a market value of 4.2B€.

EU-28 market potential	Cumulative market size	Market value	H2 Volume
2017	1500 MW	2.6 B€	200 ktons/year
2025	2800 MW	4.2 B€	400 ktons/year

Bankability boundary conditions:

Average electricity cost of 40-50 €/MWh or lower (incl. grid fees, taxes & levies), depending on country-specific regulations.

Enhancing conditions for replication:

- *Access to curtailed RES at a price discount of 60% compared to the system price;*
- *Partial exemption from grid fees, taxes & levies.*
- *Recognition of green H_2 as compliance option in Fuel Quality Directive*

Policy options to realize this market potential

Business cases replicability relies on:

1 Low-cost electricity

→ **Exemption from grid fees, taxes or levies**
A (partial) exemption can be justified by the grid-beneficial mode of operation of electrolysers
→ **Avoid inflating electricity prices with costs unrelated to electricity supply**

→ **Access to curtailed electricity**
Bilateral contracts between RES operators and consumers can lead to lower electricity price
→ **Provide a clear regulatory framework on how to access curtailed RES electricity**

2 Access to grid service revenues
→ Electrolysers can provide grid frequency control when allowed for loads, with more benefits in asymmetric procurement
→ **Develop EU framework guidelines to provide a level playing field for access to grid frequency control services**

3 Recognition as green hydrogen
→ Power-to-hydrogen electrolysers can provide gas with low carbon intensity
→ **Provide a level playing field for the injection of carbon lean gas into gas grid**, be bio-methane or green hydrogen
→ **Recognize green hydrogen as compliance option to reduce carbon intensity of conventional fuels** in the forthcoming revisions of the FQD and RED II